NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 4059

NOISE SURVEY OF A FULL-SCALE SUPERSONIC TURBINE-DRIVEN PROPELLER UNDER STATIC CONDITIONS

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Langley Field, Va.

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SUMMARY

Overall sound-pressure levels and frequency spectra of the noise emitted from a full-scale, 7.2-foot-diameter, 3,500-rpm, three-blade, supersonic propeller mounted on a turbine-powered airplane have been obtained under static conditions at stations about the propeller at a 100-foot radius.

The results of this investigation are compared with the results of NACA Technical Note 3422 for a propeller of conventional design. The comparison shows that the high-rotational-speed propeller produced an overall sound-pressure level of approximately 14 decibels more at the maximum-level station than the low-rotational-speed propeller. The spectrum of the noise of the high-rotational-speed propeller is generally flatter than the spectrum of the low-rotational-speed propeller, and the second, third, fourth, and fifth harmonics are higher than the first harmonic. The low-rotational-speed propeller displayed the maximum level in the first harmonic with a rapid drop in sound-pressure levels as the order of the harmonic increases.

Variations in power produced, in general, the variations in overall sound-pressure levels predicted by theory. The effect of a power increase on the spectrum of the noise is to raise the levels of the lower harmonics A small reduction in the overall sound pressure was obtained by lowering the propeller tip Mach number from 1.2 to 0.99; the reduction was in agreement with the scale-model results of NACA Report 1079. Analysis shows the noise reduction was afforded by reductions in the noise levels of the harmonics above the third harmonic.

INTRODUCTION

The National Advisory Committee for Aeronautics is conducting a flight research program on a number of propeller designs expected to be applicable to the high powers and high speeds of turbine-powered airplanes. In addition to yielding general propeller information, the program affords an excellent opportunity to investigate the sound levels and directional characteristics of the sound of full-scale propellers under static conditions. This type of information is of interest especially in the high tip Mach number range where results are generally obtained from scale-model investigations. (See ref. 1.)

The present investigation was conducted with a propeller designed so that the blade sections can operate above the critical speed and, thus, at optimum advance angles. This supersonic design procedure is expected to produce the ultimate in propeller efficiency but it does this at the penalty of a higher propeller noise level than the conventional-propeller design procedure, where the major portion of the blade sections is kept at subsonic speeds.

The propeller investigated is designed for a forward Mach number of 0.95 at an altitude of 40,000 feet. The propeller is capable of absorbing 2,500 horsepower under sea-level conditions. The results are compared with the results of a propeller of conventional design (ref. 2).

SYMBOLS

b	blade width (chord), ft
D	propeller diameter, ft
h	blade-section maximum thickness, ft
M_t	Mach number of propeller tip
n	propeller rotational speed, rpm
P	power absorbed by propeller, hp
R	propeller tip radius, ft
r	radius to blade element, ft
β	blade angle, deg

APPARATUS AND TEST PROCEDURE

In the present investigation a three-blade 7.2-foot-diameter propeller with a supersonic blade design was mounted on a conventional airplane as shown in figure 1. The blade-form curves and pertinent dimension ratios of the propeller are given in figure 2. The power plant for the propeller is a turbine engine geared for this test to drive the propeller clockwise at 3,500 rpm at 98 percent of the rated engine speed (14,300 rpm). The noise output of the turbine engine is considered negligible as compared with the propeller noise output for this investigation. Special torque and thrust recording equipment installed in the airplane was used to obtain the horsepower and thrust during engine operation.

Sound recordings were taken at various azimuth-angle stations on a 100-foot-radius circle about the propeller hub. The 0° azimuth station is located directly ahead of the airplane with other azimuth stations numbered clockwise from this station. Except for the recordings made at two stations (105° and 255°) at heights of 2, $3\frac{1}{2}$, and 5 feet above the ground, all recordings were made at ground level. The location selected for the sound measurements was a concrete apron with no buildings or other large reflective surfaces within 300 yards. The sound-recording and allied equipment was located 50 feet forward of the 0° station.

The operating conditions were varied during the investigation to enable sound measurements to be made at two stations (105° and 255°) to show effects of engine rotational speed, power, and position of the microphone above the ground. The radial distribution was recorded during one continuous engine run, in which the engine speed was 1,400 horsepower and the propeller speed was 3,500 rpm. The test conditions and results of the noise analysis are given in table I. Other pertinent information is as follows:

Clearance of ground by propeller, ft	2.4
Wind from 0° to nose, knots	3 to 6
Temperature, $^\circ$F	77
Barometric pressure, in. Hg	30.16

The noise-recording and analyzing equipment was essentially the same as the equipment discribed in detail in reference 2. The recordings were made with the aid of two crystal-type microphones, and the outputs of these microphones were recorded on separate channels on magnetic tape for subsequent analysis. Simultaneous recordings were made with the two microphones at stations symmetrically spaced about the airplane (for example, 105° and 255°). The recordings at the 0° station therefore show the general agreement between the two channels.

RESULTS AND DISCUSSION

Distribution of Overall Sound-Pressure Levels

Overall sound-pressure-level (root-mean-square pressure) measurements are shown in figure 3 as the distribution of the sound-pressure levels about the propeller at a 100-foot radius. Included in the figure are the levels obtained from the analysis of the tape recording of the 7.2-foot three-blade supersonic propeller and the levels obtained from a 10-foot four-blade conventional propeller (ref. 2) operating in the same power range (levels corrected for distance). The 10-foot propeller used for comparison is typical of present-day propellers in which conventional design procedures have been utilized to keep the major portion of the blade sections at subsonic speeds.

The sound-pressure levels about the supersonic propeller have an unsymmetrical distribution with the higher levels displayed to the right of the fuselage center line. The maximum sound-pressure levels occur in the propeller plane, and the sound-pressure levels are 131.5 decibels at station 90° (right of the fuselage center line) and 129 decibels at station 270° (left of the fuselage center line). The sound-pressure levels remain high up to about 30° ahead of the propeller plane (2-decibel drop) where the levels drop rapidly to 112 decibels at the fuselage center line. Behind the propeller, the maximum pressure level drops approximately 4 decibels in the right quadrant and 7 decibels in the left quadrant.

The comparison between the propellers shows that the penalty in overall sound-pressure levels under static conditions, incurred by utilization of the supersonic-section design procedure, amounts to roughly 14 decibels at the maximum-level stations. The 14-decibel penalty is slightly high as the difference measured was between a three-blade supersonic and a four-blade subsonic propeller. The subsonic propeller would produce a slightly higher sound-pressure level in a three-blade configuration. Both propellers display an unsymmetrical distribution of overall noise levels about the fuselage center line with the maximum levels to the right of the fuselage. The supersonic propeller, however, produces an unsymmetrical distribution of a lesser degree than the conventional propeller, with the highest levels in the plane of the propeller. The conventional propeller has the highest levels slightly to the rear of the propeller plane.

The unsymmetrical distribution of the noise about the center line of the airplane in the present investigation and in reference 2 is thought to be caused by two possible effects. One of these effects is the multiple reflections off of the unsymmetrical protuberances about the nose of the airplane. The other effect is the variations of pressure on the blades during a revolution; these variations of pressure result from the ground plane creating inflow dissymmetries. The small ground clearance has a greater effect on the inflow to the subsonic propeller (1-foot clearance) than on the supersonic propeller (2.4-foot clearance) and is believed to create the relatively larger unsymmetrical distribution of the noise of the subsonic propeller.

As a matter of interest, the microphone height above the ground was varied at two stations, 105° and 255°. These measurements are presented in table I. Because of the apparent complexity of the reflections, the information available at this time is insufficient to lead to any conclusions.

Distribution of Sound-Pressure Levels for the First Four Propeller Harmonics

The distribution of the sound-pressure levels for the first four propeller harmonics is shown in figure 4. Included in the figures are the measured sound levels obtained from the present supersonic propeller and the levels obtained from the subsonic propeller of reference 2; these levels are corrected for distance.

The general unsymmetrical distribution is shown for the first four harmonics with the higher levels to the right of the fuselage center line. Aside from the generally higher sound-pressure levels displayed by the supersonic propeller, the main difference shown between the two propellers is the general order of magnitude of the sound-pressure levels with the propeller harmonics. The conventional propeller shows the normal highest noise level in the first harmonic and a rapid dropoff with the higher harmonics. The supersonic propeller, however, shows the highest levels in the second and third harmonics. The general difference in the spectra of the two propellers is better shown in figure 5 where the spectra measured at station 105° are shown for both propellers. It can be seen that the harmonic content of the supersonic propeller is such that the second, third, fourth, and fifth harmonics are higher than the first. Whereas, for the subsonic propeller the spectrum shows a rapid dropoff of sound-pressure level with order of harmonic to the extent that harmonics higher than the fourth are out of the limits of the analyzer-equipment settings. The analyzer equipment is limited to a total range of 20 decibels for any one setting. An attenuation is selected to get the maximum sound-pressure level within the range; the lower limits are therefore raised or lowered according to the attenuations necessary for the peak pressures. Figure 5(b) shows the sound-pressure levels present in the two propellers at higher frequencies. Individual propeller harmonics are lost in this presentation because of the large filter-band width (200 cps at half-power level) used during this part of the analysis. The spectrum of the 10-foot propeller in figure 5(b) is a fairing of the data of reference 2.

Effect of Power

The overall sound-pressure levels and the frequency spectra of the noise measured at station 105° are shown in figure 6 for power settings of 550, 850, 1,400, and 2,100 horsepower. Propeller rotational speed was maintained at 3,500 rpm for each power setting. The spectrum points are connected by straight lines in this plot strictly for ease of identification.

An increase in power from 550 to 850 horsepower lowers the level by $1\frac{1}{2}$ decibels to 127 decibels. Increasing the power from 850 to 1,400 horsepower raises the sound-pressure level by 4 decibels to 131 decibels. A further increase in the power to 2,100 horsepower raises the sound-pressure level an additional 2 decibels to 133 decibels. Except for the first power increase the increases are, within the accuracy of the measurement, in agreement with the theoretical increase in overall sound-pressure levels with increase in power. The spectra of the noise measured at the different power settings show a consistency with power settings only for the first harmonic. The second harmonic shows the same reduction in pressure level with an increase in power from 550 to 850 horsepower, with consistent increases with further power increase, as was shown for the overall noise levels. For higher harmonics no general trend is followed. With large power variations large variations occur in inflow, spanwise loading, and chordwise pressure distributions. Reference 3 shows that the harmonic content of the noise emitted from a propeller can change as a function of the chordwise pressure distributions; this may account for some of the apparent inconsistences of the data of figure 6.

Briefly, the effect of power increase is to raise the lower harmonic content of the spectrum. Although large variations exist in the higher harmonics, no consistent change with power exists.

Effect of Propeller Rotational Speed

During ground operations one solution to the high noise levels of supersonic propellers is to operate at reduced rotational speeds. In order to show the effects of a rotational-speed reduction on the noise output, runs were made in an attempt to duplicate powers at two rotational-speed settings. The settings at 3,500 and 2,900 rpm produce the tip Mach numbers of 1.2 and 0.99, respectively. The noise spectrum of several runs is plotted in figure 7. The reduction from 3,500 to 2,900 rpm lowers the overall noise levels by about 3 decibels. The 3-decibel reduction in overall noise level with reduced tip speed is in agreement with the scale-model tests of reference 2. From figure 7 it is seen that the reduction is caused by the rapid drop in sound-pressure levels above the third harmonic. A greater reduction in tip Mach number than that obtained in the present investigation would be necessary to have a satisfactory noise reduction for ground operations. This further reduction should produce a spectrum similar to that of the conventional propellers, or one that has a maximum level in the first harmonic with rapid drop in sound-pressure levels as the order of the harmonic increases. With the engine and gear box used in the present tests, propeller rotational speeds below 2,900 rpm are not attainable without large reductions in the horsepower input to the propeller.

CONCLUDING REMARKS

Tape recordings of the noise emitted from a 7.2-foot-diameter, 3,500 rpm, three-blade, supersonic propeller have been made under static conditions at stations about the propeller at a 100-foot radius. The tape recordings at each station have been analyzed to obtain overall sound-pressure levels and frequency spectra.

Results of the analysis are compared with the results of a 10-foot-diameter 4-blade propeller tested and discussed in NACA Technical Note 3422. The 10-foot propeller is of conventional design and is typical of present-day-transport propellers. The comparison shows that the penalty in overall sound-pressure levels under static conditions, incurred by utilization of the supersonic-propeller design procedure, amounts to roughly 14 decibels at the maximum-level stations. Both propellers display unsymmetrical distribution of overall noise levels with the greater noise levels to the right of the fuselage center line. The supersonic propeller, however, produced an unsymmetrical distribution of a less degree than the subsonic propeller, with the highest levels in the propeller plane. The subsonic propeller has the highest levels to the rear of the propeller plane. The difference in the degree of unsymmetry is thought to be due in part to the relatively larger ground clearance of the supersonic propeller as compared with the subsonic propeller.

The harmonic content of the noise of the two propellers differed greatly. The high-tip-speed (supersonic) propeller produces a generally flatter spectrum than the low-tip-speed propeller with the second, third, fourth, and fifth harmonics higher than the first harmonic. The low-tip-speed (subsonic) propeller displayed the maximum level in the first harmonic with a rapid drop in sound-pressure level with increase in order of harmonic.

Varying the power to the supersonic propeller in general produces approximately the variation in overall sound-pressure level predicted by theory. The effect of a power increase on the spectrum of noise is to raise the level of the lower harmonics.

A small reduction in the overall sound-pressure level was obtained by lowering the propeller tip Mach number from 1.2 to 0.99; the reduction was in agreement with the scale-model results of NACA Report 1079. Analysis shows that the noise reduction was afforded by reductions in the noise levels of the harmonics above the third harmonic.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 22, 1957.

REFERENCES

1. Hubbard, Harvey H., and Lassiter, Leslie W.: Sound From a Two-Blade Propeller at Supersonic Tip Speeds. NACA Rep. 1079, 1952. (Supersedes NACA RM L51C27.)

2. Kurbjun, Max C.: Noise Survey of a 10-Foot Four-Blade Turbine-Driven Propeller Under Static Conditions. NACA TN 3422, 1955.

3. Watkins, Charles E., and Durling, Barbara J.: A Method for Calculation of Free-Space Sound Pressures Near a Propeller in Flight Including Considerations of the Chordwise Blade Loading. NACA TN 3809, 1956.

TABLE I

TEST CONDITIONS AND RESULTS OF NOISE ANALYSIS FOR A SUPERSONIC PROPELLER

Test conditions			Sound-pressure level, db (Reference pressure level, 0.0002 dynes/cm^2)									Remarks
Station, deg	Microphone height above ground, ft	P, hp	Overall	Order of harmonic								
				1st	2d	3d	4th	5th	6th	7th	8th	
330	0	1,400	111.0	105.0	105.0	104.0	105.0	101.0	95.0	93.5	93.5	Polar distribution: constant power; continuous run; 3,500 rpm; M_t = 1.2; right microphone
0	0	1,400	112.0	95.0	105.0	103.0	105.5	103.0	102.0	97.0	97.0	
30	0	1,400	114.0	99.0	100.0	104.5	105.0	104.0	103.5	106.5	106.5	
60	0	1,400	130.0	109.0	125.0	124.5	122.0	113.5	112.5	103.0	111.0	
90	0	1,400	131.5	115.0	127.5	123.0	122.5	115.5	119.5	119.0	111.0	
105	0	1,400	131.0	118.0	128.5	123.0	118.5	121.0	117.0	114.0	108.0	
120	0	1,400	129.0	121.5	125.0	122.0	110.0	106.5	108.5	108.5	106.0	
135	0	1,400	127.5	121.5	124.0	118.5	117.5	109.5	108.5	105.5	103.0	
30	0	1,400	113.0	106.5	100.5	107.5	104.5	105.0	97.0	98.5	96.5	Polar distribution: constant power; continuous run; 3,500 rpm; M_t = 1.2; left microphone
0	0	1,400	113.0	97.0	105.5	103.0	104.5	100.0	100.5	100.0	98.5	
330	0	1,400	113.0	107.0	100.0	108.0	100.0	101.0	96.0	97.5	95.5	
300	0	1,400	127.0	104.0	116.0	119.5	120.5	116.5	114.0	107.0	-----	
270	0	1,400	129.0	113.0	119.0	123.0	120.5	111.0	108.0	117.0	114.0	
255	0	1,400	129.0	120.0	123.0	122.5	118.0	113.5	111.5	106.0	103.0	
240	0	1,400	126.5	121.0	123.0	118.0	112.0	107.0	104.5	108.0	104.0	
225	0	1,400	122.0	115.5	117.5	116.0	103.5	102.0	100.0	100.0	99.0	
105	0	550	128.5	114.0	123.0	118.0	120.5	123.0	115.0	-----	115.0	Power varied: 3,500 rpm; M_t = 1.2
255	0	550	124.0	106.0	112.0	116.0	117.5	113.0	110.5	101.0	105.5	
105	0	850	127.0	115.5	121.5	118.5	118.5	121.0	107.5	111.5	116.0	
255	0	850	128.0	115.0	121.0	119.0	123.5	112.0	111.0	113.0	114.0	
105	0	2,100	133.0	124.0	130.0	122.0	113.0	123.0	118.0	110.0	120.0	
255	0	2,100	129.0	121.0	124.5	122.0	118.0	116.0	116.5	114.0	112.0	
105	0	200	119.0	101.5	103.5	110.0	113.5	108.0	104.5	109.5	105.0	Power varied: 2,900 rpm; M_t = 0.99
255	0	200	120.5	109.5	108.0	114.5	115.0	102.5	109.0	108.5	101.0	
105	0	360	128.0	115.5	111.5	112.5	123.5	114.0	113.5	113.5	115.0	
255	0	360	124.0	115.5	116.5	118.0	107.0	111.0	112.0	106.0	107.0	
105	0	600	122.0	115.0	115.5	116.5	112.0	106.5	107.5	104.0	108.0	
255	0	600	115.0	108.0	106.0	106.0	109.5	104.0	100.0	100.0	99.0	
105	0	1,050	125.0	118.0	120.0	119.0	112.0	108.0	118.0	111.0	107.5	
255	0	1,050	121.0	112.5	113.0	113.0	115.5	111.0	104.0	98.0	-----	
105	2	1,400	131.5	121.5	127.0	125.5	115.0	120.0	119.5	113.5	-----	Height of microphone varied: 3,500 rpm; M_t = 1.2
255	2	1,400	129.0	122.0	126.0	124.5	124.0	114.0	118.5	111.0	112.0	
105	$3\frac{1}{2}$	1,400	131.5	124.5	123.5	126.0	119.5	117.0	121.0	116.0	-----	
255	$3\frac{1}{2}$	1,400	129.0	121.5	125.0	115.0	112.0	112.5	-----	117.0	111.5	
105	5	1,400	131.0	123.5	123.5	125.0	120.5	120.0	119.0	117.5	110.5	
255	5	1,400	127.5	121.5	122.0	116.5	107.0	111.0	110.0	118.5	113.0	

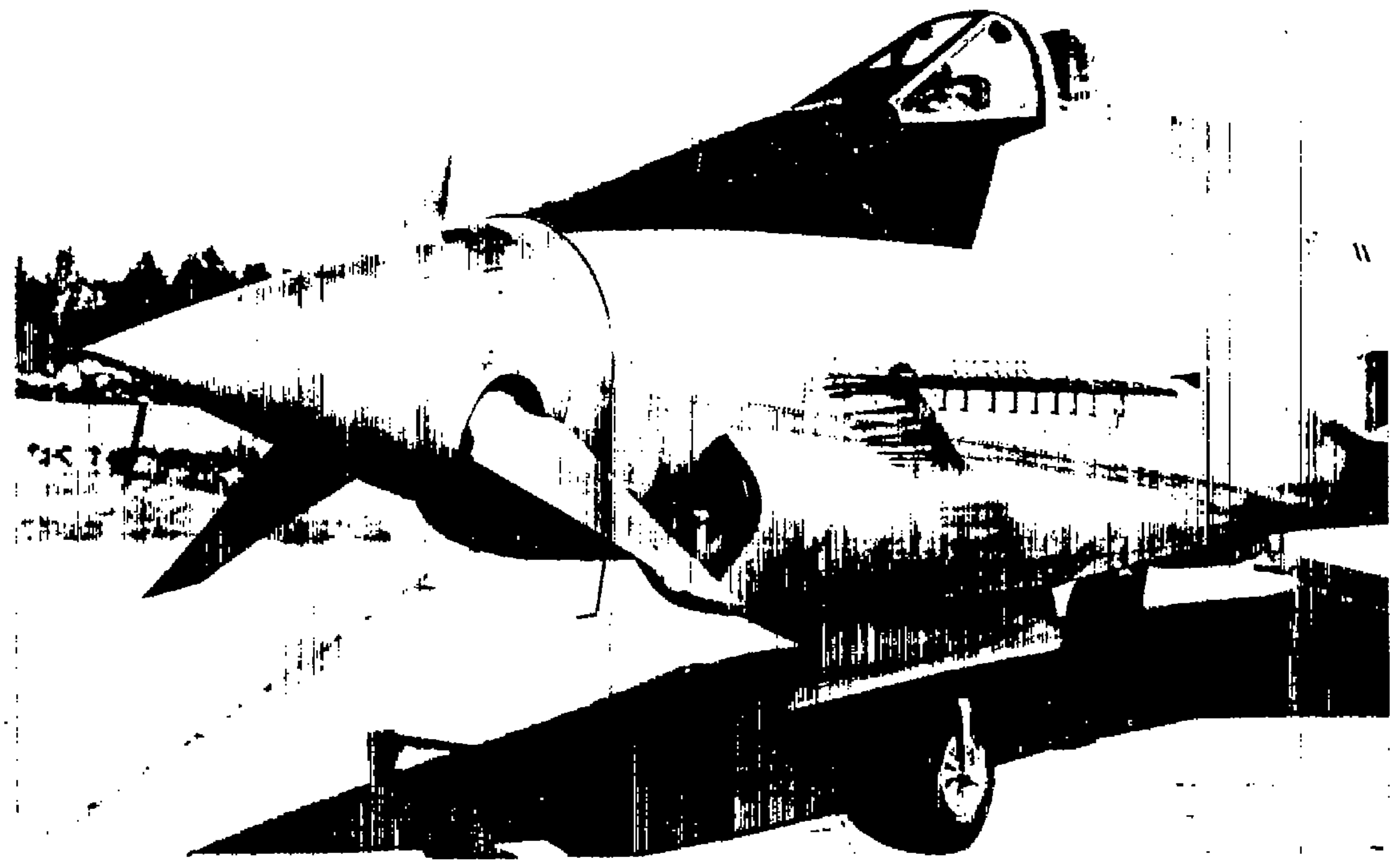

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Figure 1.- The 7.2-foot-diameter three-blade propeller mounted on a turbine-driven airplane.

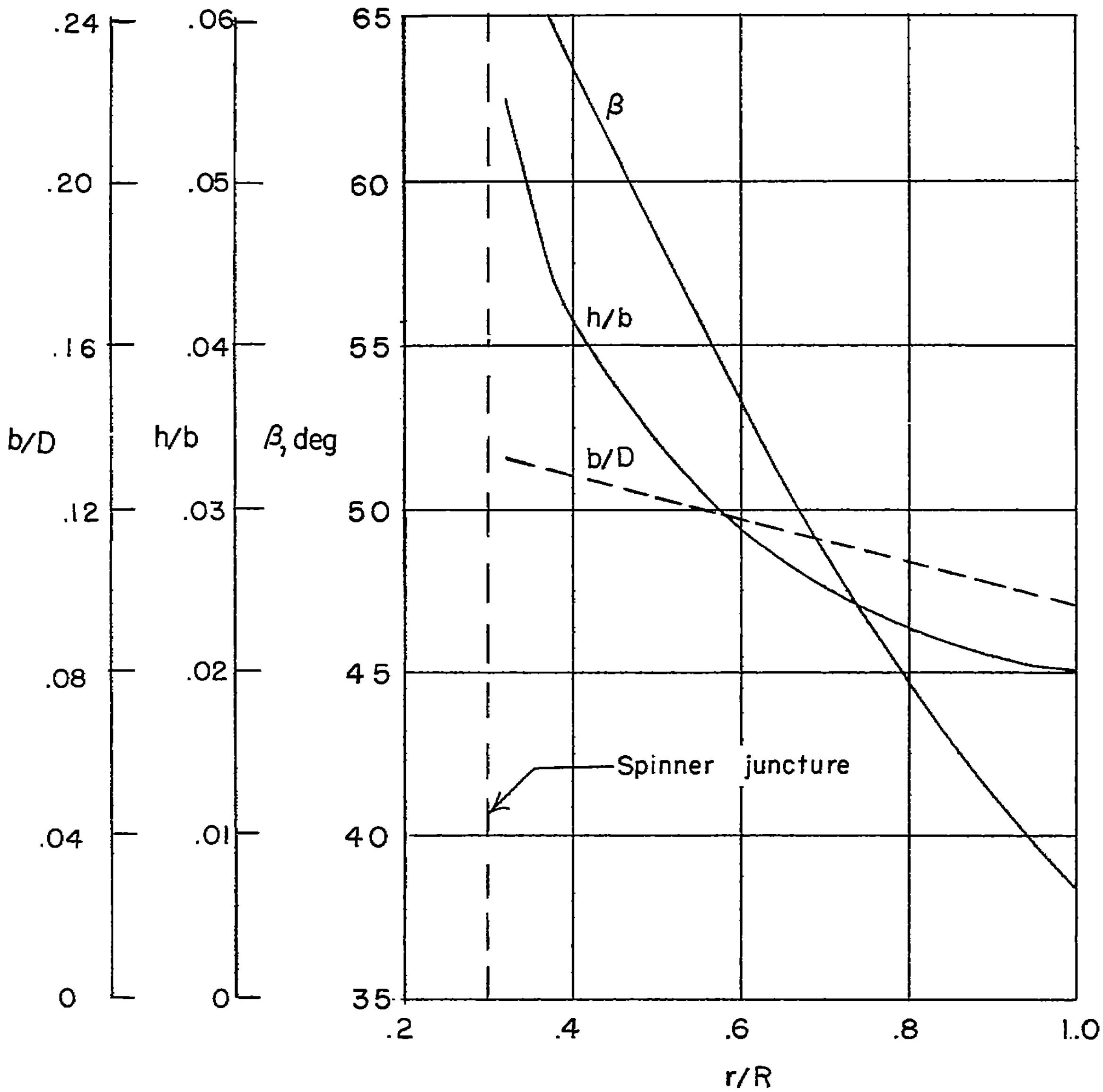


Figure 2.- Blade-form curves of the 7.2-foot-diameter three-blade propeller used in the present investigation.

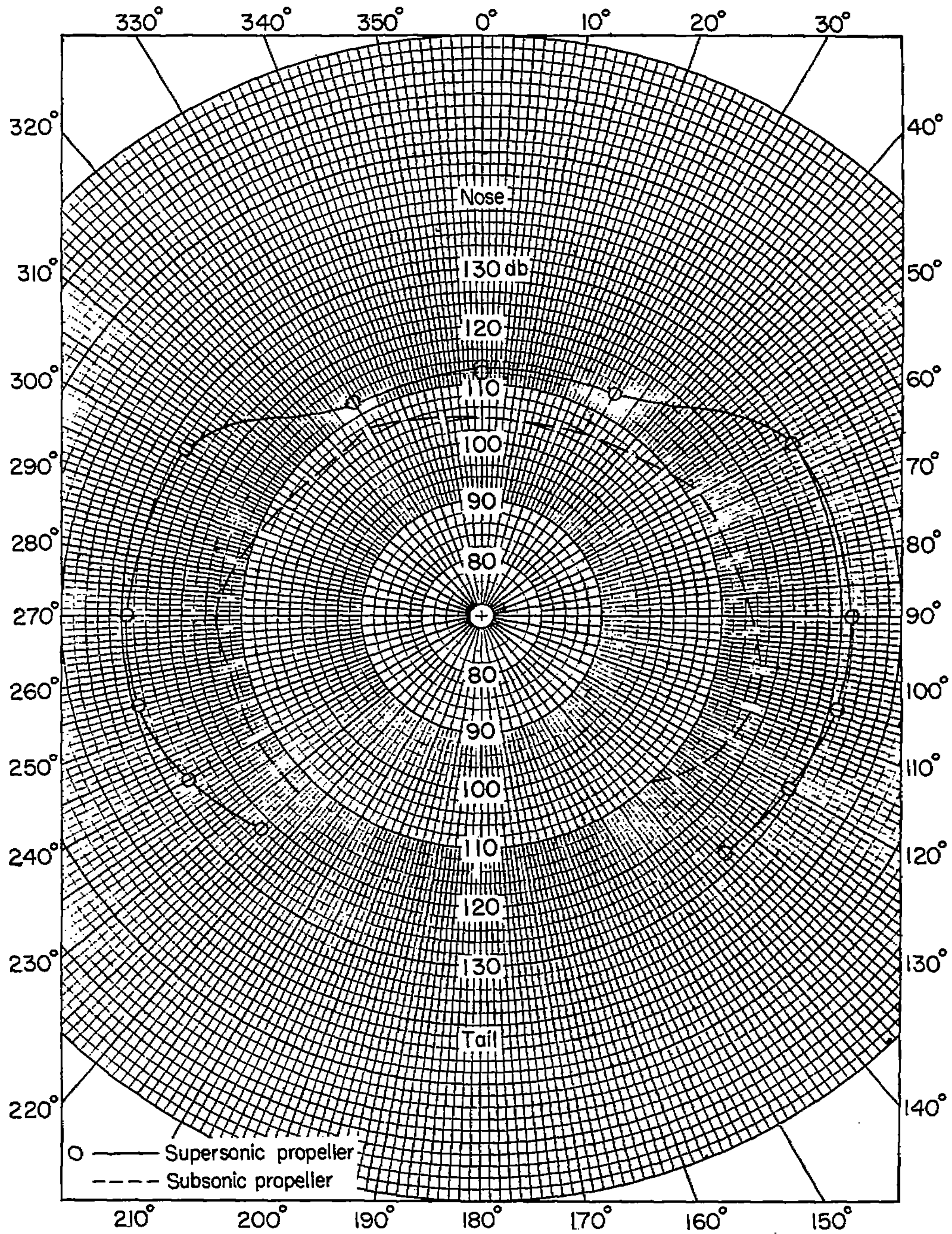
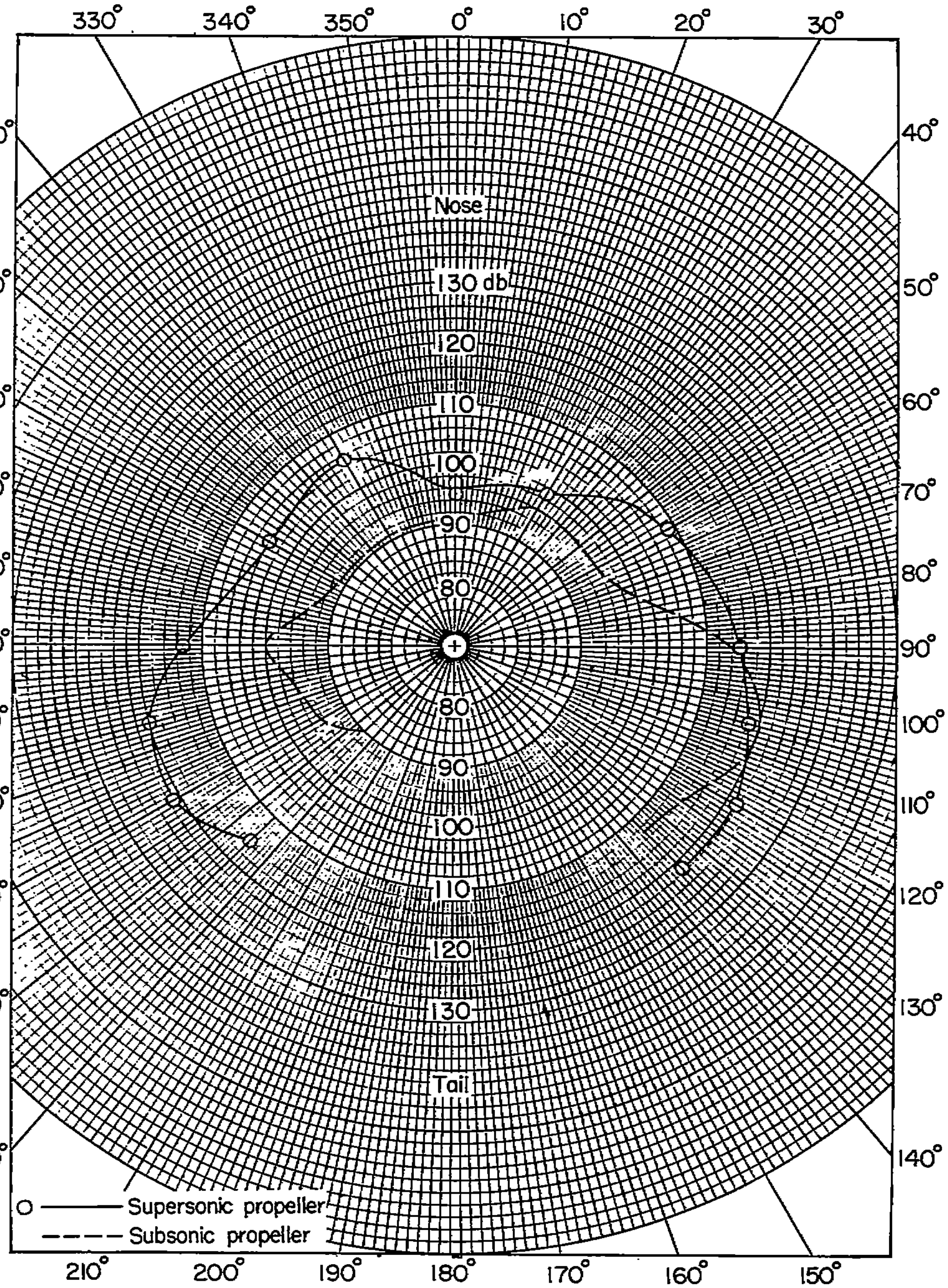
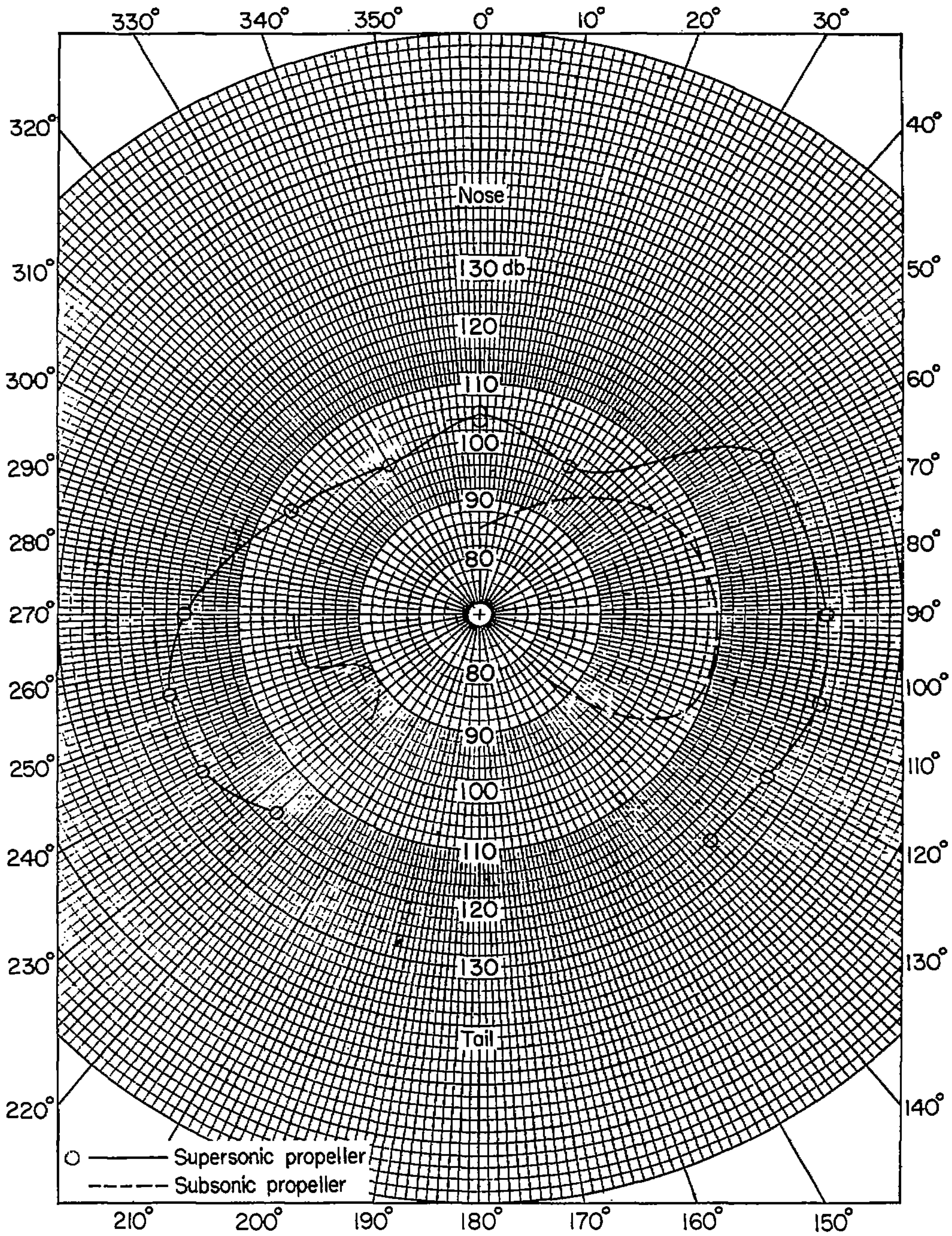


Figure 3.- The overall sound-pressure levels at a 100-foot radius for the supersonic propeller of the present investigation and for the conventional subsonic propeller of reference 2.



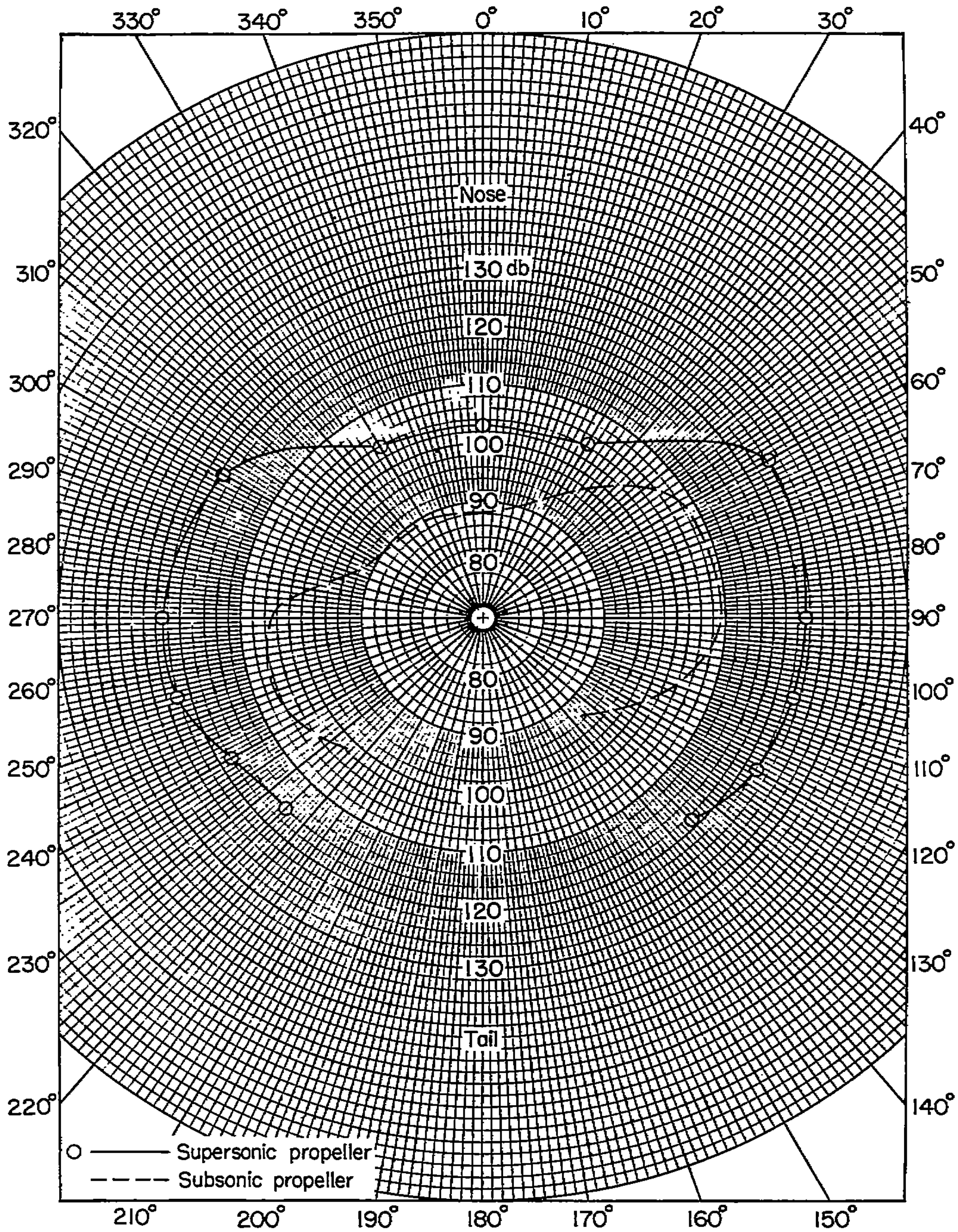
(a) First propeller harmonic.

Figure 4.- The sound-pressure levels at a 100-foot radius for the supersonic propeller of the present investigation and for the conventional subsonic propeller of reference 2.



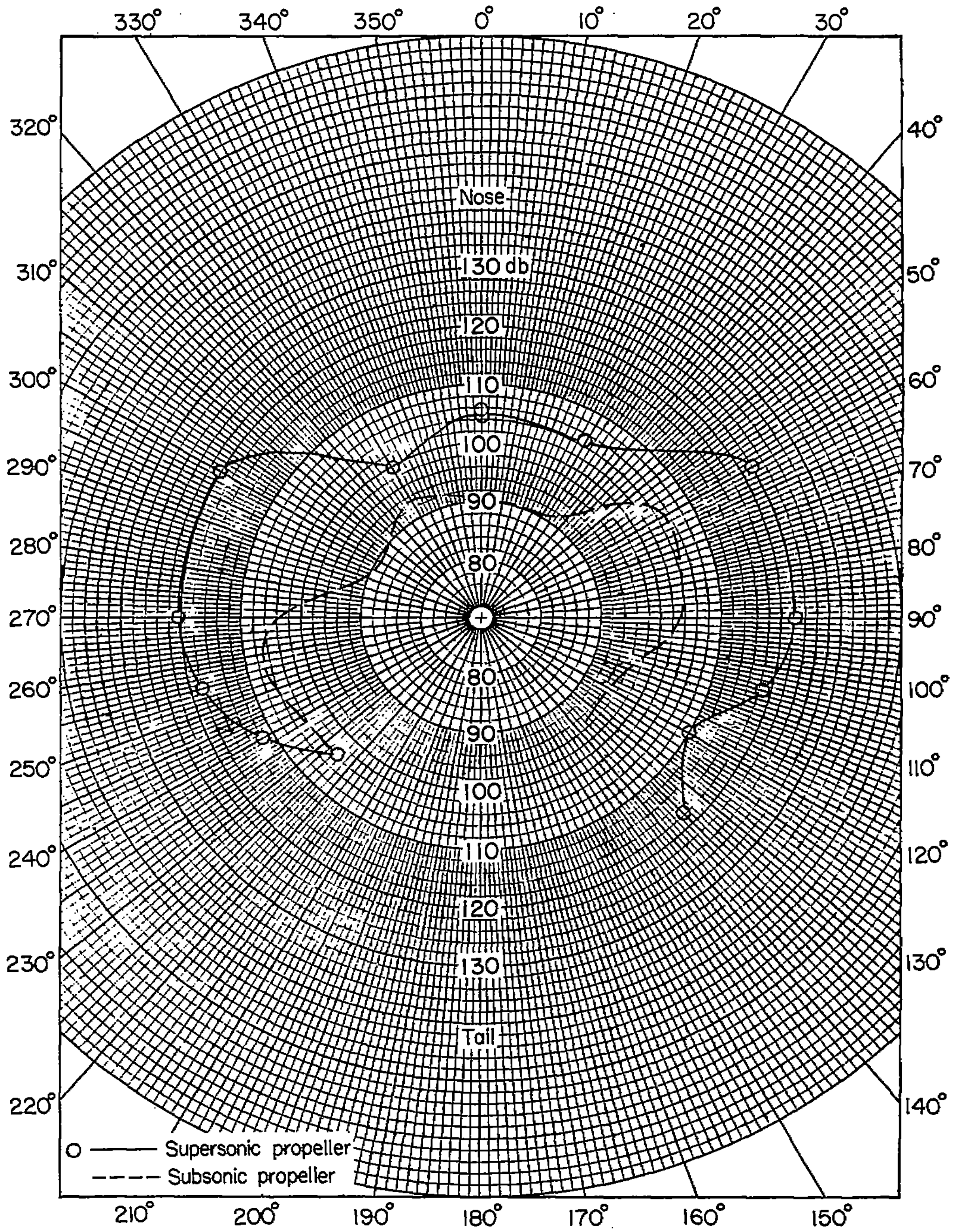
(b) Second propeller harmonic.

Figure 4.- Continued.



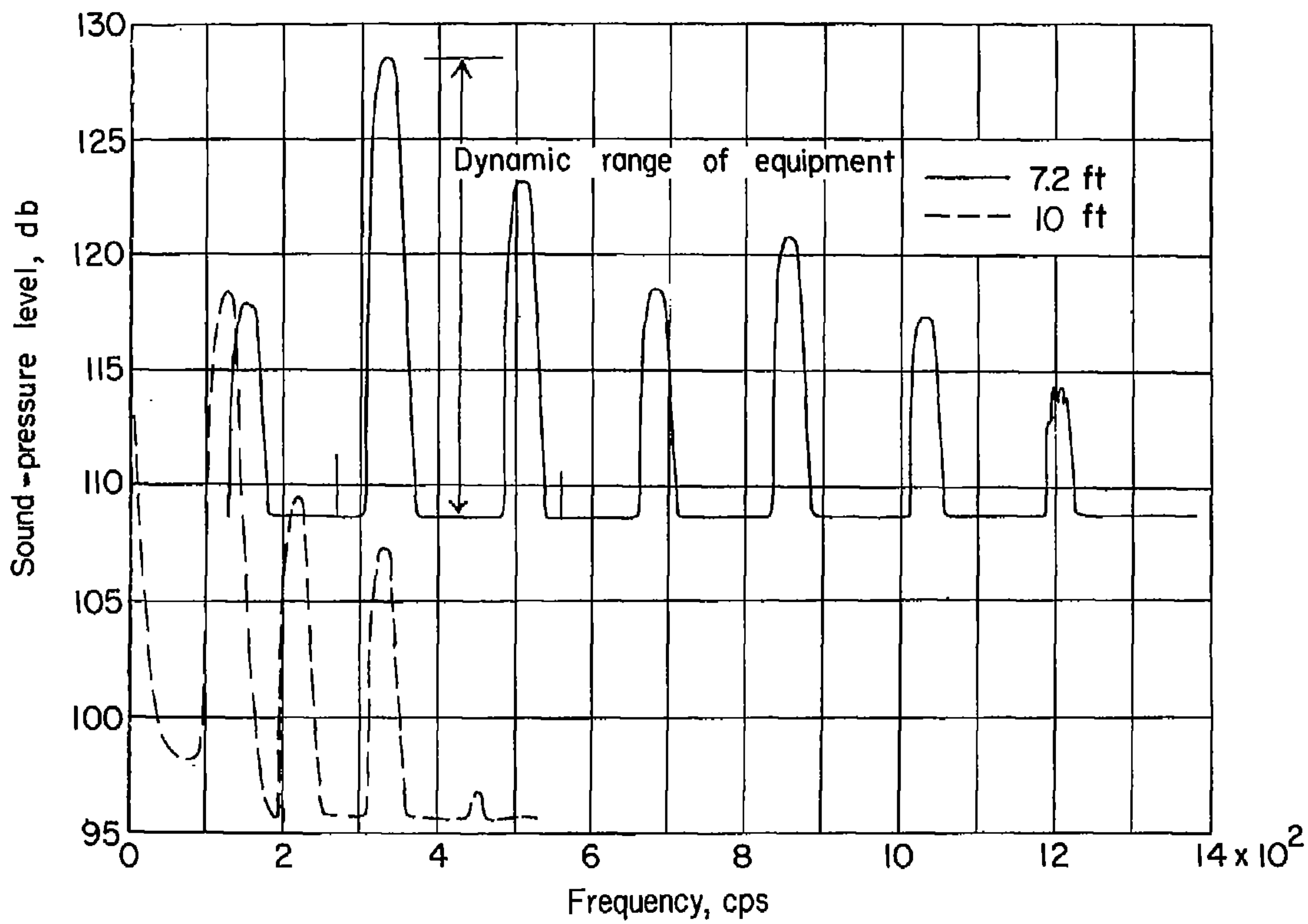
(c) Third propeller harmonic.

Figure 4.- Continued.



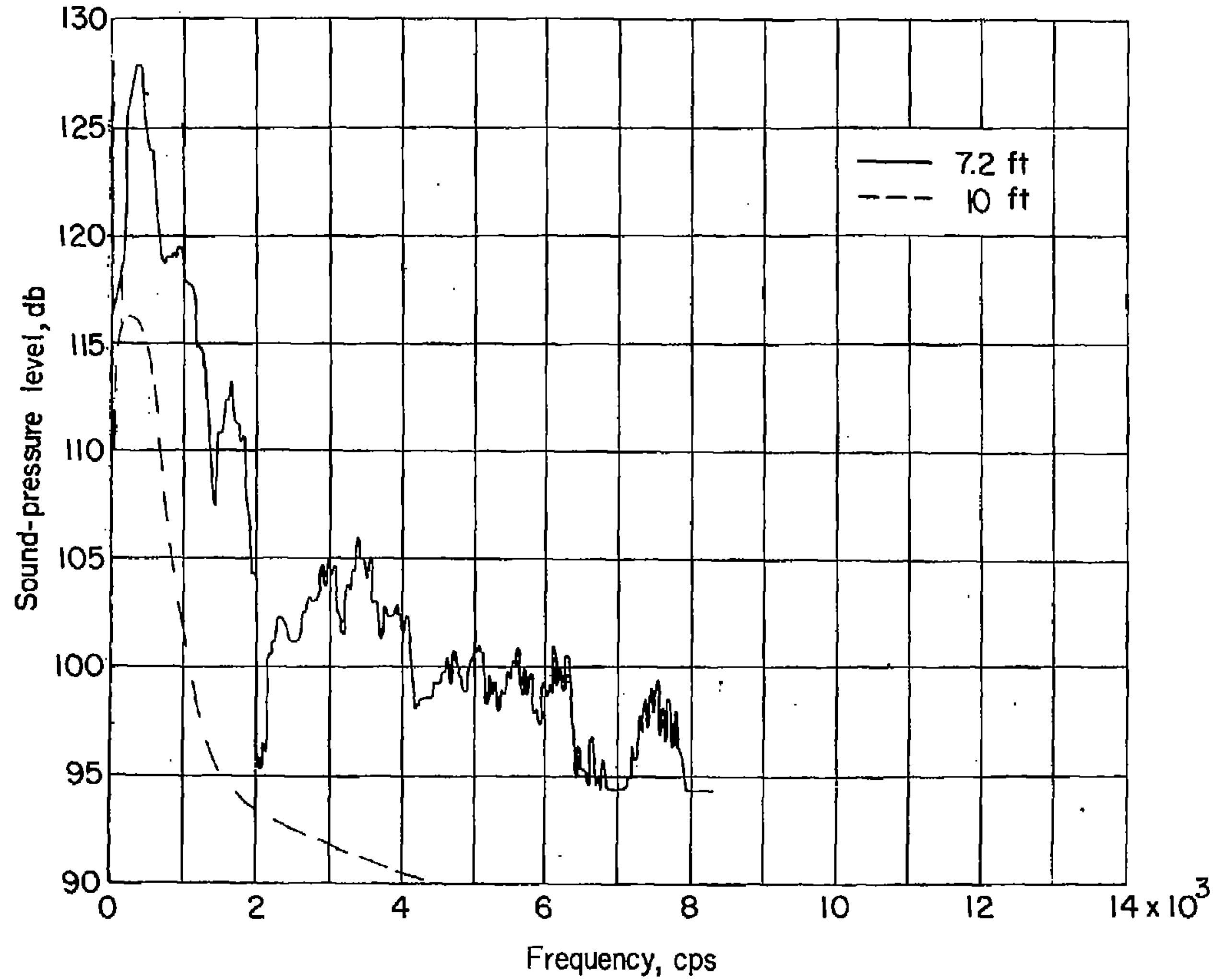
(d) Fourth propeller harmonic.

Figure 4.- Concluded.



(a) Frequency, 50 to 1,400 cps; filter-band width, 20 cps.

Figure 5.- Variation of sound-pressure levels with frequency at station 105° for the 7.2-foot-diameter supersonic propeller of the present investigation and for the 10-foot-diameter conventional subsonic propeller of reference 2.



(b) Frequency, 50 to 14,000 cps; filter-band width, 200 cps.

Figure 5.- Concluded.

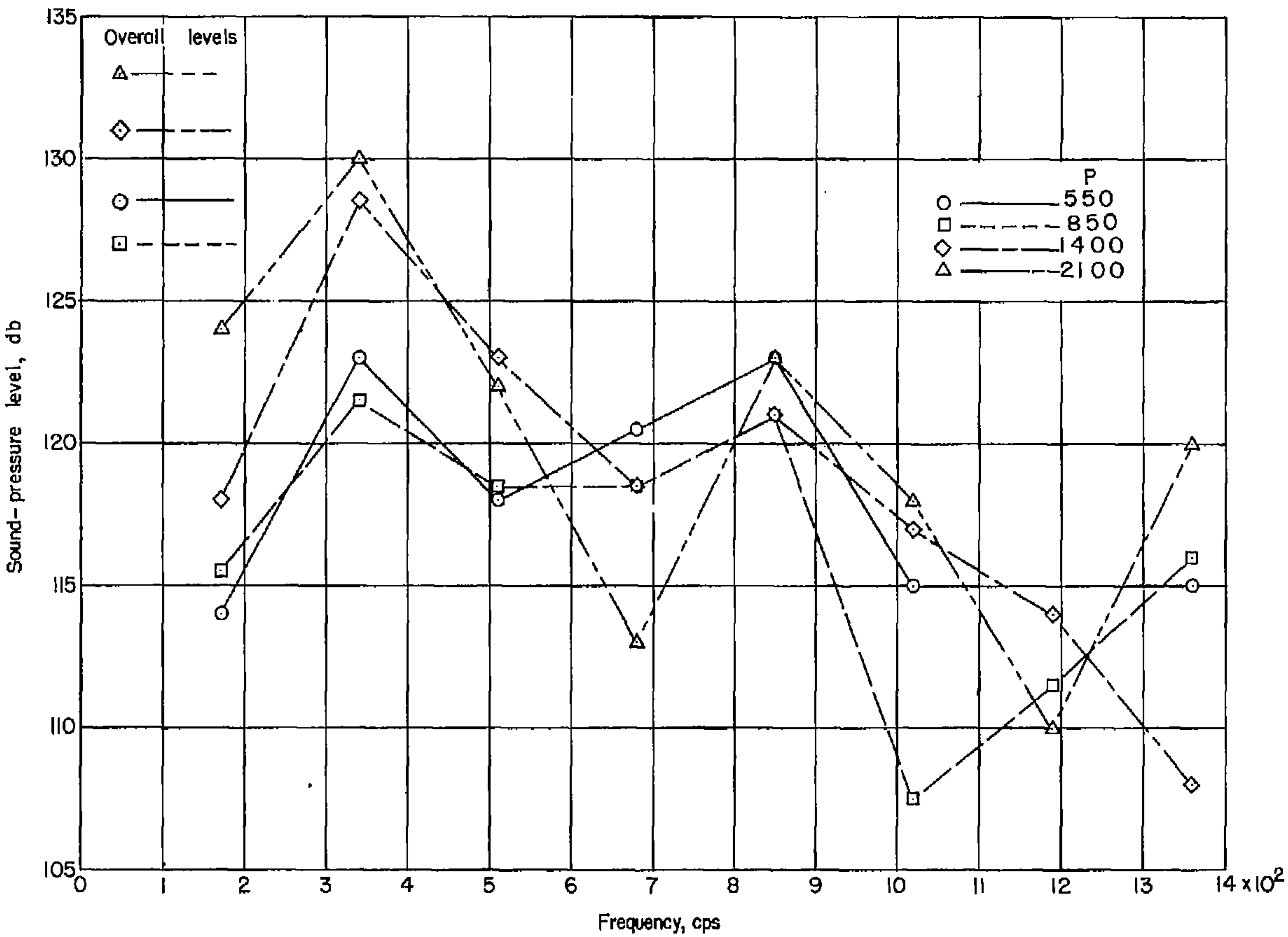


Figure 6.- The variation in sound-pressure levels with frequency at station 105° for several power settings. Propeller rotational speed, 3,500 rpm.

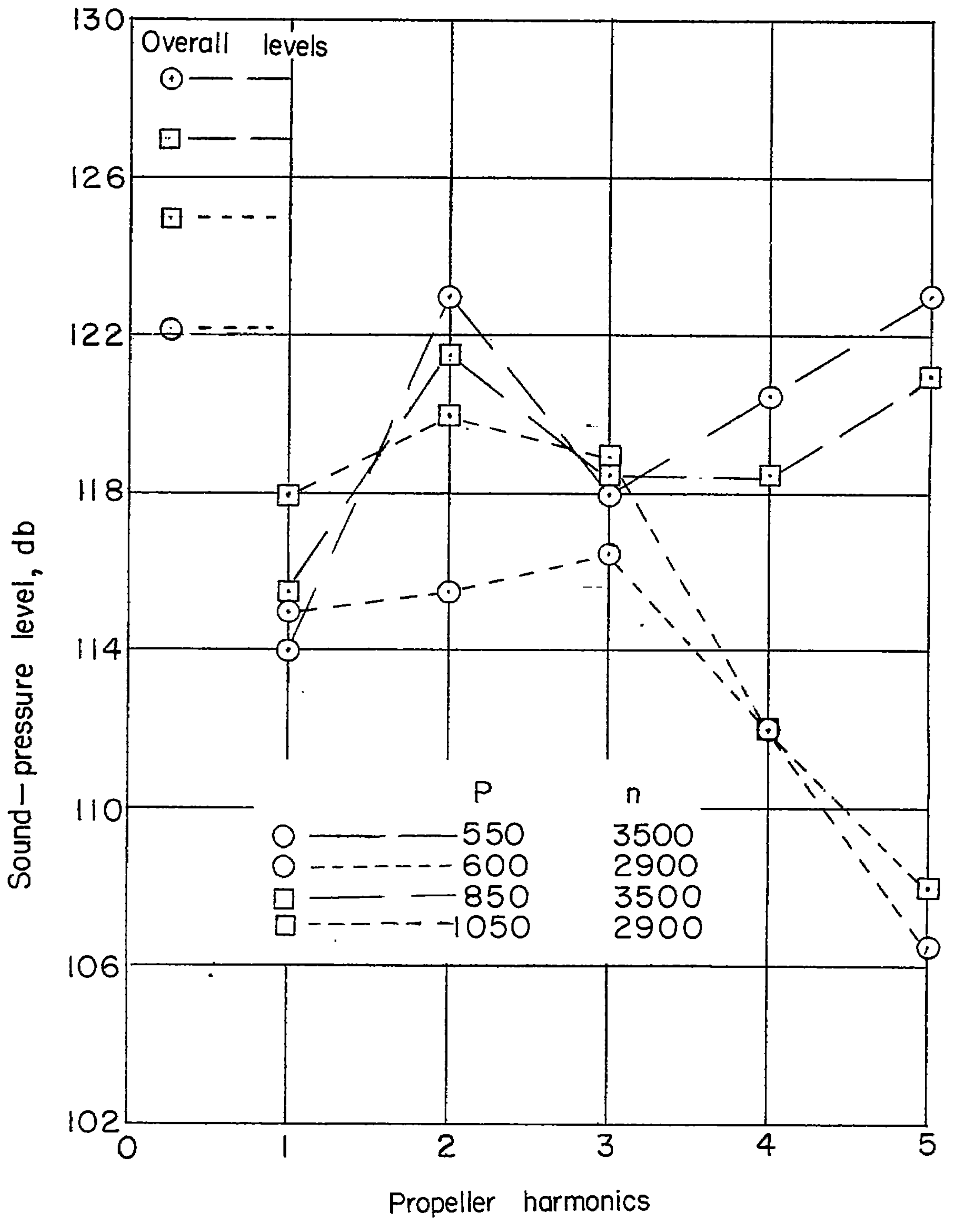


Figure 7.- The variation in sound-pressure levels with order of harmonics at near duplicate powers for two rotational-speed settings.